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The Effect of Silane Modified Kaolin on Rheological Properties

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THE EFFECT OF SILANE
MODIFIED KAOLIN ON
RHEOLOGICAL PROPERTIES

BY

JAMES KUHAGEN

A THESIS SUBMITTED IN PARTIAL
FULFILLMENT OF THE COURSE
REQUIREMENTS FOR THE
BACHELOR OF SCIENCE DEGREE

WESTERN MICHIGAN UNIVERSITY
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ABSTRACT

It is well known that increased latex usage in pigmented coatings will enhance strength properties. However, the increase will result in lower optical properties. A modified pigment could be advantageous in the binding of adhesive, where as at present a film formation and secondary forces are major influences in the colloidal system.

Preliminary results indicate silane coupling agents were compatible in the rheological systems studied. In addition, care should be exercised in the selection of an adhesive for a specified situation.

These positive results form a sound basis for further investigation of organofunctional silanes as coupling agents in a coating system.

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LITERATURE REVIEW

RHEOLOGICAL CONCEPTS^{3,4}

The topic of rheology is presented here as an aid in and/or review of the fundamental concepts of rheology. An in depth study of these concepts is beyond the scope of this paper. However, such concepts as viscosity and types of rheological flow will assist in the correlation of these concepts to modified kaolin systems.

Viscosity is defined as the proportionality constant between shear force and shear rate. On the other hand, rheology is the study of changes in the relationship between shear force and shear rate.¹

There exists a diversified classification of rheological types of flow, which for the purpose of this paper will be broken into two categories; shear dependent and time dependent. Shear dependent flow, as its name implies, lends itself to variations in resistance to flow as shear rate is varied. For simplification, the less found, or rare types of flow will only be mentioned. These types of flow are Bingham body, which is an idealized type of flow, and Rheopexy, a complex, not well understood, type of flow.¹

Pseudoplastic flow is a more common type of flow, and is commonly referred to as shear thinning. In other words, viscosity is reduced by increased shear. Its counterpart, shear thickening, or dilatent systems,

is an increase in the resistance to flow as the shear rate increases. Following, plastic flow, which is relatively related to the Bingham body flow, is a less idealized type of flow. This type of flow exhibits a linear function between shear force and shear rate until reaching a yield point which extends out until the flow changes into a pseudoplastic type. This type of flow could be explained by a flocculated structure which is destroyed by shear, but not completely, followed by a slower destruction as shear is increased. Finally, in the shear dependent category, exists a type of flow which can be explained as the time dependent reformation of structures in the fluid as shear is decreased. This incorporates many different types of flow and may also have an alternate explanation. It also could be considered a time dependent breakdown of resistance to shear at a constant shear. This type of flow is called thixotropic and can be distinguished from other types of flow graphically. A plot of shear force versus shear rate for a time dependent rheological phenomenon will contain a hysteresis loop. Two basic types of time dependent flow are presented in this work; time dependent shear breakdown and time dependent shear buildup. Shear breakdown is the other alternative of thixotrophy. This can be related to a starch solution makedown where a gel is formed, followed by a breaking gel, and then reaching steady flow characteristics. The time dependent thickening phenomenon is not common but should be mentioned. It is the appearance of higher viscosities over prolonged periods of constant shear.

Another important rheological concept is dispersion, which has a mechanical and chemical aspect. The mechanical aspect must exert enough energy into the system to disaggregate flocculated particles. Once

separated, the particles, which normally have absorbed water on their surfaces, will re-agglomerate in the absence of a dispersant. It is evident that two major forces exist in the dispersion system. First, the attractive force, which enhances re-agglomeration, is basically van der Waals London forces and the ability of absorbed water to act as cement between the platlets. Second, a repulsive force, which comes from the introduced electrolyte or dispersant. The electrolyte causes an electrical double layer around the particle. As particles with this electrical double layer are brought closer together, the electron clouds begin to interact, and due to the electron cloud overlap, an increase in charge density occurs. This system is labeled dispersion.² The effect of dispersion on rheology can become of interest in many studies. A non-dispersed or flocculated system leads to plastic flow or a possible combination of pseudoplastic and thixotropic flows, which is an undesirable type of flow in a continuous system. On the other hand, a well dispersed system should lead to Newtonian flow. However, an overdispersed system will result in plastic and a relatively high degree of pseudoplastic flow.

CONCEPTS OF ADHESIVES⁷

For an understanding of colloidal systems attributes of the ideal adhesive are presented. These attributes consist of good bonding strength, good color and color stability, good flow characteristics, prevention of excessive migration into the body stock and a good colloidal stability during storage and are the important considerations for this text. Again, it should be emphasized that increased adhesive concentration will increase the strength of the coating but will decrease the number of air-pigment interfaces and adversely affect opacity and brightness.

Some basic fundamentals of adhesion and adhesives will help in understanding these aspects when they are related to silane chemistry and properties. First, a mention of critical pigment volume concentration. Critical pigment volume concentration is defined by TAPPI 41:743(1958); as the level of pigmentation at which just enough vehicle solids in dry film are present to fill all voids between pigment particles. It has been shown that when the pigment volume is greater than the critical pigment volume concentration, the properties of pigments will predominate and that the binder portion will act only as an adhesive between pigments.⁶ Most paper coatings are above the critical pigment volume concentration and therefore have considerable void volume present in the dried coatings. A couple factors should be emphasized at this point when dealing with adhesives. First, the importance of adhesive retention on such parameters as optical and physical properties of the film. Secondly, bonding properties of the adhesive. Readily, a direct relation in physical properties and amount of retention can be deduced where as optical properties are reliant on critical pigment volume concentration, drying rates and relation of the adhesives to the total colloidal system (i.e., thickness of adhesive layers, foam, packing arrangements).⁵

A list of factors affecting pigment bonding strength and adhesion theory would be too complex for this work. An abbreviated list is presented to point out the major concerns of adhesion in its application to silanes. Of the most important is the concept of specific adhesion. It is a theoretical measurement of bonding between pigment and adhesive and between substrate and adhesive. Continuing the substrate geometry (i.e., pore size, orientation of affected molecules and the amount of penetration

to the substrate) will affect bonding strength and adhesion because of alignment parameters.⁶ Again the adhesive must be able to "wet" the surface of pigment and fiber, which implies the occurrence of contact on the molecular level.

Adhesive bonds not being as strong as predicted can be attributed to such parameters as lack of molecular interactions, internal stresses as a result of volume changes on drying the adhesive and substrate, surface contamination, swelling of the solid substrate by the adhesive, time factors for complete wetting and molecular diffusion of large polymers. In adhesion the reactive groups for selected molecules are; cellulose fibers which bond by mostly hydrogen bonding through hydroxyl groups, starch through hydroxyl groups, pigments because of their high polarity. However, latices have a low specific adhesion, but the bonds formed are highly flexible and relatively more elastic as compared to natural binders. Caution must be taken in the formulation of synthetic adhesives so that an abundance of attractive groups is avoided. If unavoids, the molecule will stiffen and less energy will be required to break bonds (i.e., decrease in coating strength).⁸

Synthetic Adhesives

Basic to the understanding of silanes in the coating system is an understanding of latices which will be used for this laboratory study. The basic nature of latices is a stable dispersion of rubber-like material in an aqueous medium which contains surface activating agents, electrolytes, protective colloids, catalyst residues, in an emulsion polymerization. The latex must contain functional groups which are capable of adhering to

pigment and raw stock. A latex particle is roughly 1/25th of the size of a clay platlet.⁸

The characteristics of latex adhesives exhibit good strength, flexible films, water resistance, high smoothness development, low viscosity at high solids and high molecular weight, and good dimensional stability. On the other hand, higher cost, poor water retention, opacity loss, and a poor pigment disperser, are disadvantages of latices in the coating system. However, latex is a growing trend in industry and its contributions to the coating system are multiple.

SILANES¹⁰

Before understanding the chemistry of silanes a brief study of silicon is presented. Elementary silicon lies in the second short period on the periodic chart. Therefore, its maximum covalency is six. However, silicon found in laboratory chemistry has shown tetravalent properties.⁹ The difference between silicon chemistry and carbon chemistry lies in the covalent properties. However, a link between silicate chemistry and organic chemistry is shown in the study of organosilicon compounds. These compounds are capable of forming polyorganosiloxanes which range from R_4Si to $(SiO_4)^{-4}$ where the functionality is determined by the free valences of the oxygen atom. This gives rise to the application of "Silane" for SiH_4 which was first proposed by Stock by analogy to alkanes. Also, the terms silanol and disiloxane were proposed by Stock.⁹

Functional silanes are silanes with unsaturated or functionally substituted hydrocarbon radicals. The variability to these functional groups impart important characteristics to the silane. Of major concern are the functional groups that lend themselves to use as coupling agents.

Silanes as coupling agents have bifunctional characteristics. First, they have the ability to bond to inorganic compounds and secondly, have the capability of bonding to organic polymer matrices. Since kaolin has an unreactive silica sheet surface which implies poor crosslinking with conventional elastomer polymers, a reaction between silanes and silica sheet surfaces may be beneficial.

The general structure of organofunctional silanes is $(RO)_3 SiR'X$; where X is a group attached by a carbon-carbon bond which has functional properties. R' is usually a normal propyl group, and RO is a hydrolyzable alkoxy group. This group is responsible for the chemical bond to the silica sheet surface via a silanol (H_3SiOH) condensation reaction. These reactions leave a chemically bound, unreacted organic functionality.

The blending of silanes is achieved most efficiently by dry blending. The silanes are not put in solution as they can react with each other and form coagulated stable products which would adversely effect the coating system. This dry blending method requires high shear and can be at room or elevated temperatures.

The functional groups left unreacted in the silanol condensation have not been extractable by extraction techniques.¹¹ These unreacted organic groups can then further react with polymer matrices by addition to double bonds, displacement of chloride ions, condensation with isocyanates, and reaction with saturated polymers. An attribute of the organic functional silane is its ability to maintain reactivity over long term storage periods, and again is not extractable from the inorganic surface after these extended periods.¹²

MODIFIED KAOLINS

Modified kaolins have been shown by electron microscopy to have smoother sheet surfaces than unmodified clays.¹³ These micrographs might prove helpful in the interpretation of experimental data. Keeping the dispersion theory in mind, a silane with the proper organic functionality may be chosen to impart antropic repulsion characteristics to the silica sheet surface. The functionalities of known dispersants are amide amine phenol hydroxyl carboxyl ester ether nitrile phenyl. Therefore, a silane with a properly selected functional group may prove to be helpful in the rheological system by eliminating the need of dispersants which have an effect on the shear planes.

The size of the latices in relation to clay platlets may be of some concern in the determination of the optimum amount of silane to be reacted with the kaolin. Remembering that the clay surface is smooth upon silane modification, the mechanism for film formation of adhesives, presented by Vanderhoff and Bradford, TAPPI, April, 1963, may be affected by changes in surface tension parameters. The sequence of events for film formation given above is as follows: First, the evaporation of water which enables the coagulation of particles after the solid volume reaches approximately 75 percent. At this point, surface tension forces resin particles in the adhesive closely together. Then if the particles are above glass temperature, they fuse by cold flow, and finally, the destruction of shape and hence the formation of film.

STATEMENT OF PROBLEM

Upon indepth study of the literature, it is apparent that organo-functional silanes are effective coupling agents. The functional groups indicate the ability to impart dispersion characteristics to clay. In addition, the proper choice of functionalability may increase the bonding strenght to an adhesive.

Since a rehological study is very complex, it will be advantageous to use a simplified model to detect the presence of any trends in the data. Further experimentation may then be based on the presence or absence of any of these trends.

The model chosen for this study contains a brief examination of dispersion, wet out properties (i.e., aggregate size), and flow patterns. These three examinations should indicate the compatibility of organofunctional silianes in a coating system.

EXPERIMENTAL DESIGN

INTRODUCTION

The basis for this experimentation lies in the following objectives. First, determine the optimum dispersant levels for each modified clay based against a standard clay. Second, determine the degree of dispersion. Third, obtain rheograms for each clay for the determination of flow patterns.


The standard clay was Hydragloss, which is a number one fine clay and is manufactured by the Huber Company. It was selected because it is the base clay used in the silane modification by Dow Chemical Company.

METHODS

The kaolins under study are summarized in Table 1. The procedure for determining the optimum dispersant level was as follows:

1. Disperse each clay in water without dispersant at seventy-one percent solids for twenty minutes with a dispersator.
2. Measure the viscosity of the clay with a brookfield viscometer. (Procedure detailed in Appendix 1.)
3. Add 0.02%, based on dry weight of clay, of a ten percent TSPP solution and mix in the dispersator for five minutes.

TABLE 1

<u>Experimental Designation</u>	<u>Functionality</u>	<u>Name</u> <u>Formula</u>
HYDRAGLOSS	-	HYDRAGLOSS
C-1	EPOXY	GLYCIDOXYPROPYLTRIMETHOXY SILANE $(\text{CH}_3\text{O})_3\text{-Si-(CH}_2)_3\text{-O-CH}_2\text{-CH(CH}_2\text{)-CH}_2$
C-2	AMINO ALKYL	n-(2AMINOETHYL)-3-AMINO PROPYLTRIMETHOXY SILANE $(\text{CH}_3\text{O})_3\text{-Si-(CH}_2)_3\text{-NH-CH}_2\text{-NH}_2$
C-3	VINYL BENZYL AMINE	n-P-(n-VINYL BENZYL AMINO)ETHYL- -AMINO PROPYLTRIMETHOXY SILANE (HCL) $(\text{CH}_3\text{O})_3\text{-Si-(CH}_2)_3\text{-NH-CH}_2\text{-CH}_2\text{-NH-CH}_2\text{-}$  $\text{CH=CH}_2 \cdot \text{HCL}$
C-4	MERCAPTO	MERCAPTO PROPYLTRIMETHOXY SILANE $(\text{CH}_3\text{O})_3\text{-Si-(CH}_2)_3\text{-SH}$

4. Measure the viscosity with a Brookfield viscometer and repeat steps (3) and (4) until the addition level of TSPP reaches 0.4%, based on dry weight of clay, for each type of clay.

Upon the determination of proper dispersant concentration, master batches of each clay were made at seventy percent solids. These batches were then drawn from for the remainder of the experimentation.

A grind gauge was used to obtain a relative measure of aggregate size. The test was applied to only the pigment slurries of each clay at decreasing solid levels. (Procedure detailed in Appendix 2.)

The procedure for studying the rheological properties of each clay is outlined below:

1. Draw five 100 gram samples of each clay. The first sample is to serve as a pigment slurry blank.
2. To the remaining samples add the following adhesives at the designated levels with good mixing:

Synthetic Binders

Sample 2 - Styrene Butadine @ 15 PPH parts of dry clay

Sample 3 - Poly Vinyl Acetate @ 15 PPH parts of dry clay

Natural Binders

Sample 4 - Starch (STACO-M) @ 20 PPH parts of dry clay

(Make Down Procedure in Appendix 3.)

Sample 5 - Protein (PROCOTE LV) @ 15 PPH parts of dry clay

(Make Down Procedure in Appendix 3.)

3. Measure the solids content of each sample on a solids balance, following the procedure given by the manufacturer.
4. Obtain a rheogram from the Hercules viscometer for each sample. Follow the instruction manual given with the apparatus.
5. Repeat steps (1) thru (4) for each type of clay listed in Table 1.

The next step in the procedure was to lower the solids level of each clay, by the addition of water with moderate mixing, and follow the procedure for the study of rheological properties. The solids level of each clay was decreased by five percent until the solids level reached sixty percent.

PRESENTATION AND DISCUSSION OF RESULTS

RESULTS

The results of the dispersion study are presented in Figure 1 and Table 2. Figure 1 is the plot of Brookfield viscosity at 100 RPM versus percent dispersant based on dry weight of clay. Table 2 presents the optimum levels of dispersant derived from Figure 1.

The results of the grind gauge are given in Table 3. The values at the bottom of the Table were averaged from the three solids levels because of their consistency.

Appendix 4 presents the calculated values from the Hercules rheograms for each system. Included is a description of the type of flow. S, M, V, are symbols used for slightly, moderate, and very respectively. The thixotropic index is a measure of the degree of thixotrophy and is the linear distance between the up and down swing of the hysteresis loop at 2200 RPM. A dash represents the absence of thixotrophy and the zero represents the unrecordable presence of thixotrophy. The apparent Newtonian viscosity is calculated by the formula:

$$N = \frac{9.55 \ T \ S}{\text{RPM}}$$

where: N = the apparent Newtonian viscosity
 T = torque measured from the rheogram
 S = constant for the bob = 0.0002
 RPM = maximum revolutions per minute
 which for all tests were 4400

FIGURE 1

BROOKFIELD
VISCOSITY
@ 100 RPM
DISPERSIONS AT
70 % SOLIDS

V
I
S
C
O
S
I
T
Y
(cP)

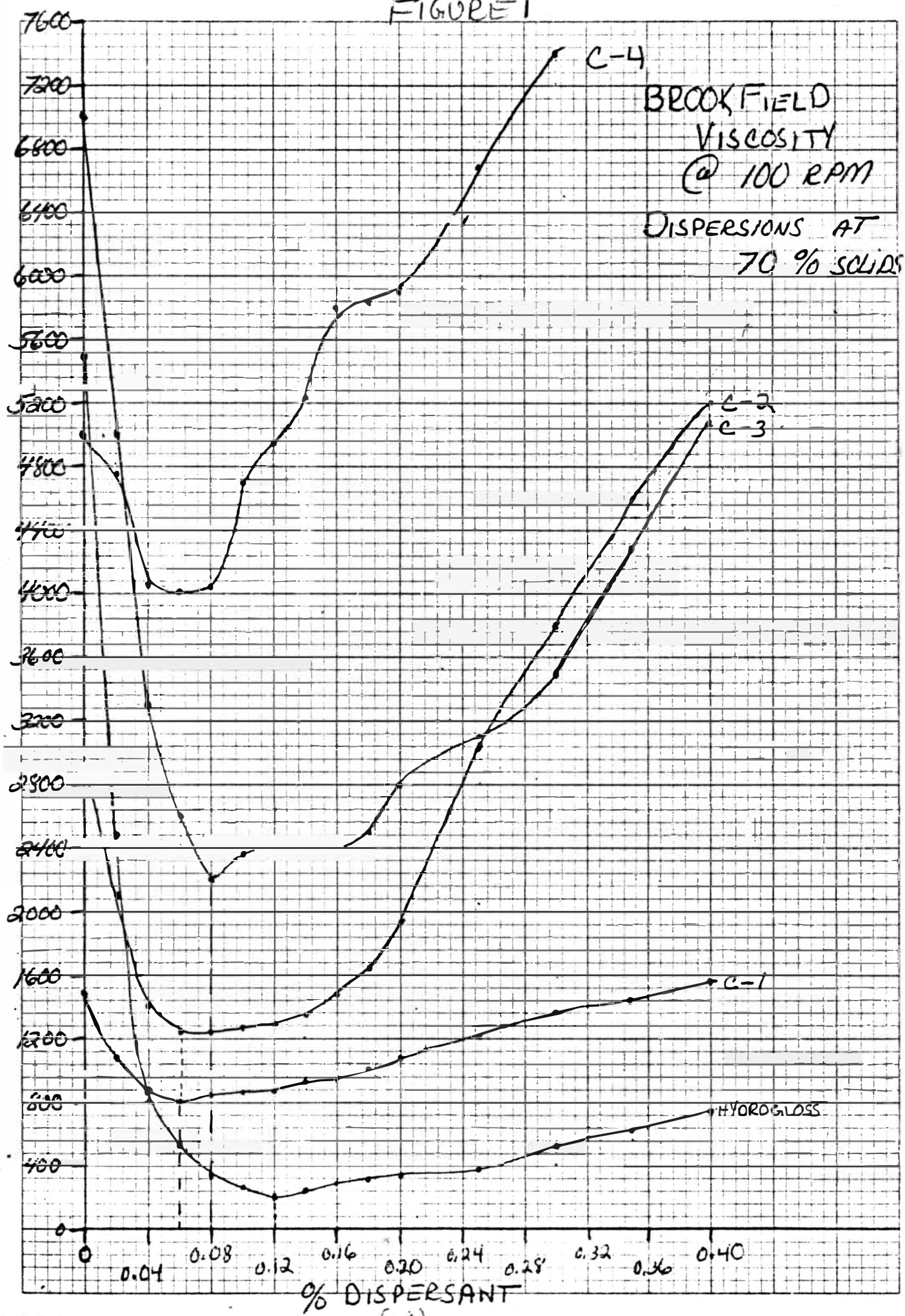


TABLE 2

OPTIMUM
LEVELS
OF
DISPERSANT

<u>CLAY</u>	<u>ADDITION LEVEL % OF DRY CLAY</u>
Hydragloss	0.12
C-1	0.06
C-2	0.06
C-3	0.08
C-4	0.06

TABLE 3

GRIND GAUGE

<u>CLAY</u>	<u>READING</u>	<u>INCHES</u> $\frac{1}{(10,000)}$	<u>SOLIDS (%)</u>
Hydragloss	0.0	0.0	60.4
C-1	0.5	1.0	60.7
C-2	2.25	4.5	59.8
C-3	2.5	5.0	60.6
C-4	1.0	2.0	60.1
Hydragloss	0.5	1.0	65.3
C-1	0.75	1.5	65.7
C-2	3.0	6.0	65.8
C-3	4.5	9.0	65.5
C-4	1.0	2.0	66.1
Hydragloss	1.0	2.0	70.1
C-1	1.0	2.0	69.9
C-2	4.0	8.0	70.1
C-3	6.0	12.0	70.3
C-4	3.0	6.0	69.4
AVERAGE			
Hydragloss	0.5	1.0	-
C-1	0.75	1.5	-
C-2	3.1	6.2	-
C-3	4.3	8.3	-
C-4	1.7	3.4	-

DISCUSSION

From the dispersion curves in Figure 1 it is apparent that the silane modified clays have a marked effect on the optimum levels of dispersant. However, the curves are obtained from only one set of data points and should not be taken as fact. The curves minimum viscosities appear to cover a span of 0.04 percent TSPP and do not exhibit a defined level of optimum addition. Presumably, a further study would have to incorporate a series of dispersion curves and statistically analyze the validity of a silane modified clay causing a decrease in dispersant levels.

DISPERSION

On the other hand, the grind gauge results exhibit continuity. The aggregate size of each slurry, when dispersed by itself, shows C-1 to be closely related to hydragloss.

The indication at this point is that C-3 will require a longer dispersion time as compared to the other modified clays. The functionality of C-3 is vinyl benzyl amine and would indicate the lack of dispersion characteristics because of the double bond in the functionality. By this reasoning, C-2 would be expected to also have poor aggregate size compared to hydragloss. As expected, the grind gauge results agreed. Hence, the assumption that C-3 will impart poor rheological properties is based on results.

Rheological Results

In the analysis of the pigment system rheograms (Appendix 4), the tendency towards decreasing degree of dilatency when the solids level is

decreased is readily apparent. At each solids level C-2 exhibits a higher apparent Newtonian viscosity. This was predicted from the dispersion curves (See Figure 1). The rheograms for a very dilatent and a slightly dilatent system are shown in Graphs 1 and 2 respectively (See Appendix 4).

In the styrene butadiene systems, again, C-2 is the clay which varies markedly from the other modified clays and the standard.

It should be pointed out that all of the modified clays in styrene butadiene systems exhibited undesirable flow characteristics at all solids levels as compared to their counterparts in the pigment system. Graph 3 (Appendix 4) shows the typical rheogram for a flow combination of plastic at low shear rates and dilatency at high shears.

In the polyvinyl acetate system the flow patterns appear to improve over the styrene butadiene system, but still have undesirable flow characteristics. Again, C-2 shows more deviation than the remaining modified clays. However, the apparent Newtonian viscosities are larger in all solids levels by a factor of approximately two.

In the starch system, the solids levels did not require dilutions from 65 percent solids. The apparent Newtonian viscosities were at approximately equal values of the polyvinyl acetate system but the starch systems exhibited more acceptable flow patterns. Graph 4 shows a typical flow pattern for the starch system.

Finally, the protein system exhibited pure plastic flow and the apparent Newtonian viscosities were in an acceptable range. Again, C-2 was the modified clay which deviated from the other silane modified clays. In all cases, the viscosity of C-2 is the greatest and when applicable, the thixotropic index was also greater. Graph 8 shows a typical plastic flow pattern for the protein system.

CONCLUSIONS

The results of the determination of optimum dispersant levels appear to exhibit a decrease in the required level of dispersant in silane modified clays. Where as the dispersion characteristics vary within the silane modified clays. The rheological properties exhibit two trends. First, a natural binder system appears to be more compatible for an actual coating system. Second, synthetic binder systems are compatible but care should be taken in choosing the proper organosilane functionality along with a proper choice of a synthetic binder.

RECOMMENDATIONS

The need for further study on the rheological properties of silane modified kaolins is supported by the results of this study. However, a more indepth study of silane functionality imparting dispersant characteristics to a kaolin would give a better look on the molecular level of dispersion. Another suggestion brought about by this study, would be to study the rheological properties of mixed binder systems.

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APPENDIX 1

The procedure outlined here ~~p~~retains to steps (1) and (2) in the dispersion study. First, the dispersator requires the use of a variac to throttle the rotation of the impeller. All mixing by the dispersator was done at a variac setting of 60.

In order to achieve an accurate reading on the Brookfield visometer, the diameter of the beaker must be large enough to eliminate wall shearing effects. For this study a 600 ml. beaker was chosen. Due to the limiting sample size received from Dow Chemical Company, the clay slurries were transferred back and forth between the dissolving beaker and the viscometer beaker. To prevent gross pigment loss the viscometer beaker was policed after each use.

As for the actual viscometer operation, the manufacturers instruction pamphlet was followed.

APPENDIX 2

The grind gauge is a metal plate which has a machined, inclined slant. The depth of the slant at the bottom or the reservoir is two thousandths of an inch. At the top the groove depth is zero. A scale of ten is marked on the side of the groove to enable accurate readings.

The procedure begins by placing a puddle of clay slurry in the reservoir and drawing the puddle towards the shallow end with the metering bar provided. The point at which the film appears to streak is where the reading is taken. Thus, the reading can readily be converted to inches.

APPENDIX 3

Starch Makedown (STAYCO-M)

1. Dissolve 180 grams of starch in cold water at 20 percent solids.
2. Heat solution gradually to the cooking temperature of 185° F.
3. Maintain at 185° F. for thirty minutes, remove from heat and let cool.

Protein Makedown (PROCOTE 2000 L.V.)

1. Dissolve 180 grams of protein in cold water at 20 percent solids.
2. Heat solution to 135° F.
3. Add 12 percent of 28 Baume ammoniac and heat to 140° F. for three minutes.
4. Cool protein to 125° F. and maintain this temperature until ready for use.

APPENDIX 4

PIGMENT SYSTEM

70% SOLIDS

Clay	Thixotropic Index (Dyne CM)	Apparent Newtonian Viscosity (Poise)	Leveling Index (Cm/SEC)	Form of Flow
Hydragloss	-	1.1855	-	(Y) Dilatent
C-1	-	2.4557	-	(V) Dilatent
C-2	-	8.5950	-	(V) Dilatent
C-3	-	4.5840	-	(V) Dilatent
C-4	-	3.2743	-	(V) Dilatent

65% SOLIDS

Hydragloss	10,000	0.1650	60,606	(S) Dilatent
C-1	15,000	0.1758	85,324	(S) Dilatent
C-2	70,000	1.4948	46,829	(V) Dilatent
C-3	15,000	0.2908	51,581	(M) Dilatent
C-4	25,000	0.1823	137,136	(S) Dilatent

60% SOLIDS

Hydragloss	0	0.1454	-	(S) Dilatent
C-1	0	0.1498	-	(S) Dilatent
C-2	0	0.1845	-	(M) Dilatent
C-3	0	0.1736	-	(M) Dilatent
C-4	10,000	0.1519	65,832	(S) Dilatent

54% SOLIDS

Hydragloss	0	0.1410	-	(S) Dilatent
C-1	0	0.1237	-	(S) Dilatent
C-2	0	0.1671	-	(S) Dilatent
C-3	0	0.1584	-	(S) Dilatent
C-4	0	0.1454	-	(S) Dilatent

5

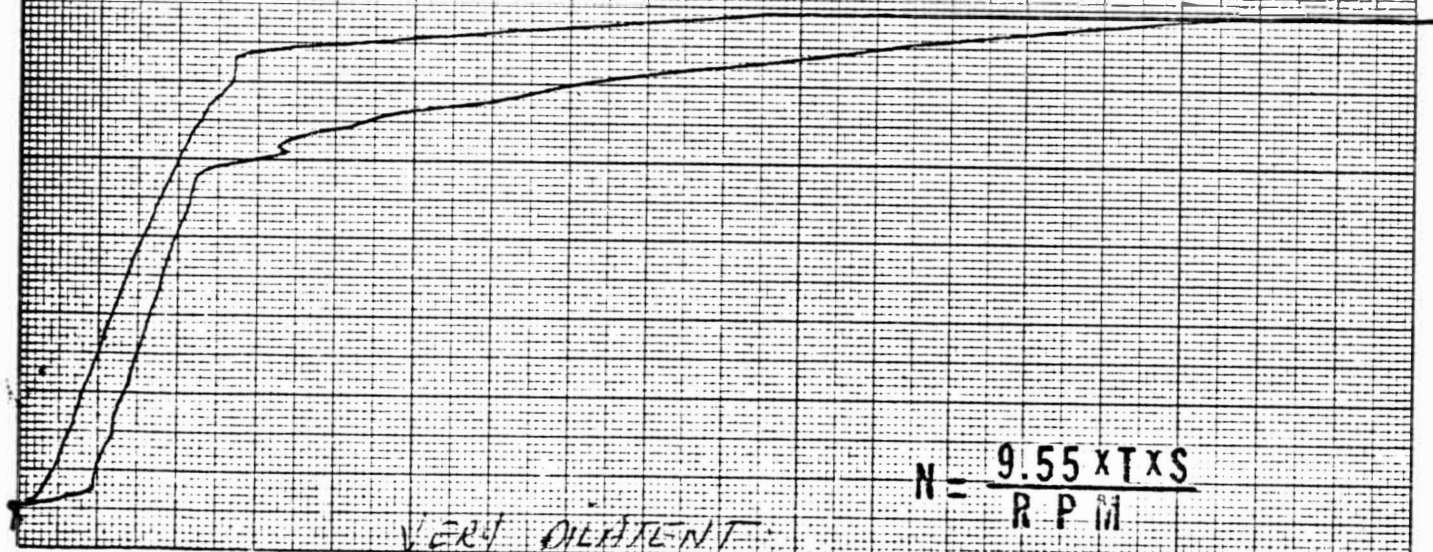
10

15

cm

C-1 SLURRY
SOLIDS 68.9%
GRAIN 1

R P M



$$N = \frac{9.55 \times T \times S}{R \times M}$$

TORQUE

KALTEC

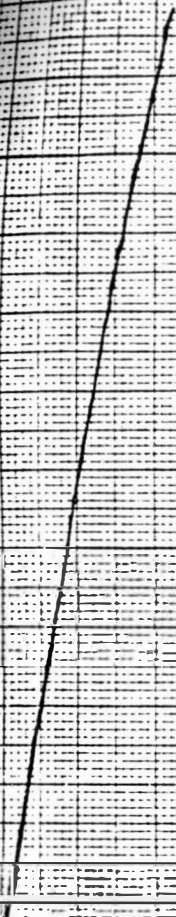
SCIENTIFIC INSTRUMENT, INC.

P.O. Box 444 • 1711 • Piquette, Michigan 48679

S	BOB HEIGHT CM	RADIUS CM	INSTRUMENT S	MAX. RATE OF SHEAR (Velocity Gradient) 1/sec.			
				390 RPM	1100 RPM	2200 RPM	4400 RPM
A	5.0	1.95	.00020	2275	4549	9098	18196
B	2.5	1.95	.00040	2275	4549	9098	18196
C	1.0	1.95	.00097	2275	4549	9098	18196
D	2.5	1.50	.00520	1935	587	774	1543

HYDROCELLS SLIPRY
SCLIDS 54.5

GENEVA



SLIGHT

DILATANT

$$N = \frac{9.55 \times T \times S}{R \cdot P \cdot M}$$

TORQUE

LITEC

SCIENTIFIC INSTRUMENT, INC.

P.O. Box 348 • 327 E. Ransom St. • Ann Arbor, Mich. 48106

BOB	BOB HEIGHT CM	RADIUS CM	INSTRUMENT S	MAX. RATE OF SHEAR (Velocity Gradient) 1/sec.			
				350 RPM	1100 RPM	2200 RPM	4400 RPM
A	5.0	1.95	.00020	2275	4549	9098	18196
B	2.5	1.95	.00040	2275	4549	9098	18196
C	1.0	1.95	.00097	2275	4549	9098	18196
D	2.5	1.50	.00520	193.5	397	774	1548
			.00008	532.6	11475	22950	45900

PIGMENT AND STYRENE BUTADIENE
66% SOLIDS

Clay	Thixotropic Index (DYNE CM)	Apparent Newtonian Viscosity (POISE)	Leveling Index (CM/SEC)	Form of Flow
Hydragloss	190,000	0.2301	825,727	Plastic
C-1	20,000	0.188	105,932	(S) Dilatent
C-2	170,000	0.2908	584,594	Plastic
C-3	125,000	0.2192	570,255	Plastic
C-4	65,000	0.1953	332,821	Plastic

62% SOLIDS

Hydragloss	0	0.1736	-	(S) Dilatent
C-1	-	0.1563	-	(S) Dilatent
C-2	80,000	0.2561	312,377	Plastic (Low) Dilatent (High)
C-3	55,000	0.1801	305,385	Plastic (Low) Dilatent (High)
C-4	-	0.1650	-	(S) Dilatent

57% SOLIDS

Hydragloss	0	0.1259	-	(S) Dilatent
C-1	0	0.1346	-	(S) Dilatent
C-2	75,000	0.188	397,245	(M) Dilatent
C-3	0	0.1432	0	(M) Dilatent
C-4	0	0.1367	-	(S) Dilatent

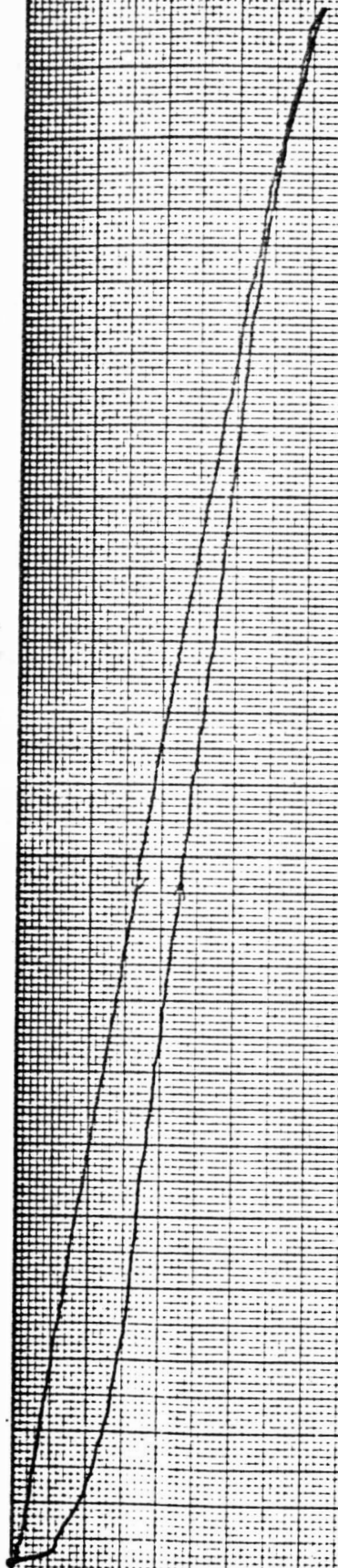
51% SOLIDS

Hydragloss	0	0.1259	-	(S) Dilatent
C-1	0	0.1194	-	(S) Dilatent
C-2	0	0.1367	-	(S) Dilatent
C-3	0	0.1324	-	(S) Dilatent
C-4	0	0.1281	-	(S) Dilatent

C-3 A 15PTS LATEX (DOW 600) (S13)
 SOLIDS 6.20%

CONCENTRATION 3

R P M



$$N = \frac{9.55 \times T \times S}{R P M}$$

PLASTIC & DILATENT

TORQUE

KALTEC

SCIENTIFIC INSTRUMENT, INC.
 P O Box 348 • 327 E Ransom St • Kalamazoo, Mich 49006

BOB	BOB HEIGHT CM	RADIUS CM	INSTRUMENT S	550 RPM	1100 RPM	2200 RPM	4400 RPM
A	5.0	1.95	.00020	2275	4549	9098	18196
B	2.5	1.95	.00040	2275	4549	9098	18196
C	1.0	1.95	.00097	2275	4549	9098	18196
D	2.5	1.50	.00520	193.5	387	774	1543
		1.00	none	5737.5	11475	22950	45900

MAX. RATE OF SHEAR
 (Velocity Gradient)
 1/sec.

PIGMENT AND POLYVINYL ACETATE
62% SOLIDS

Clay	Thixotropic Index (DYNE CM)	Apparent Newtonian Viscosity (POISE)	Leveling Index (CM/SEC)	Form of Flow
Hydragloss	100,000	0.3125	320,000	Psuedoplastic
C-1	15,000	0.5513	27,208	(M) Dilatent
C-2	80,000	0.5101	156,831	(M) Dilatent
C-3	45,000	0.5860	76,791	(M) Dilatent
C-4	205,000	0.7336	279,443	(M) Dilatent (High) Plastic (Low)

57% SOLIDS

Hydragloss	-	0.2778	-	(M) Dilatent
C-1	-	0.2170	-	(M) Dilatent
C-2	-	0.3104	-	(M) Dilatent
C-3	-	0.2453	-	(M) Dilatent
C-4	-	0.2735	-	(M) Dilatent

52% SOLIDS

Hydragloss	25,000	0.1563	159,948	(S) Dilatent
C-1	10,000	0.1541	64,892	(S) Dilatent
C-2	20,000	0.1671	119,688	(S) Dilatent
C-3	0	0.1563	-	(S) Dilatent
C-4	0	0.1519	-	(S) Dilatent

48% SOLIDS

Hydragloss	-	0.1346	-	(S) Dilatent
C-1	-	0.1389	-	(S) Dilatent
C-2	-	0.1498	-	(S) Dilatent
C-3	-	0.1411	-	(S) Dilatent
C-4	-	0.1367	-	(S) Dilatent

PIGMENT AND STARCH
51% SOLIDS

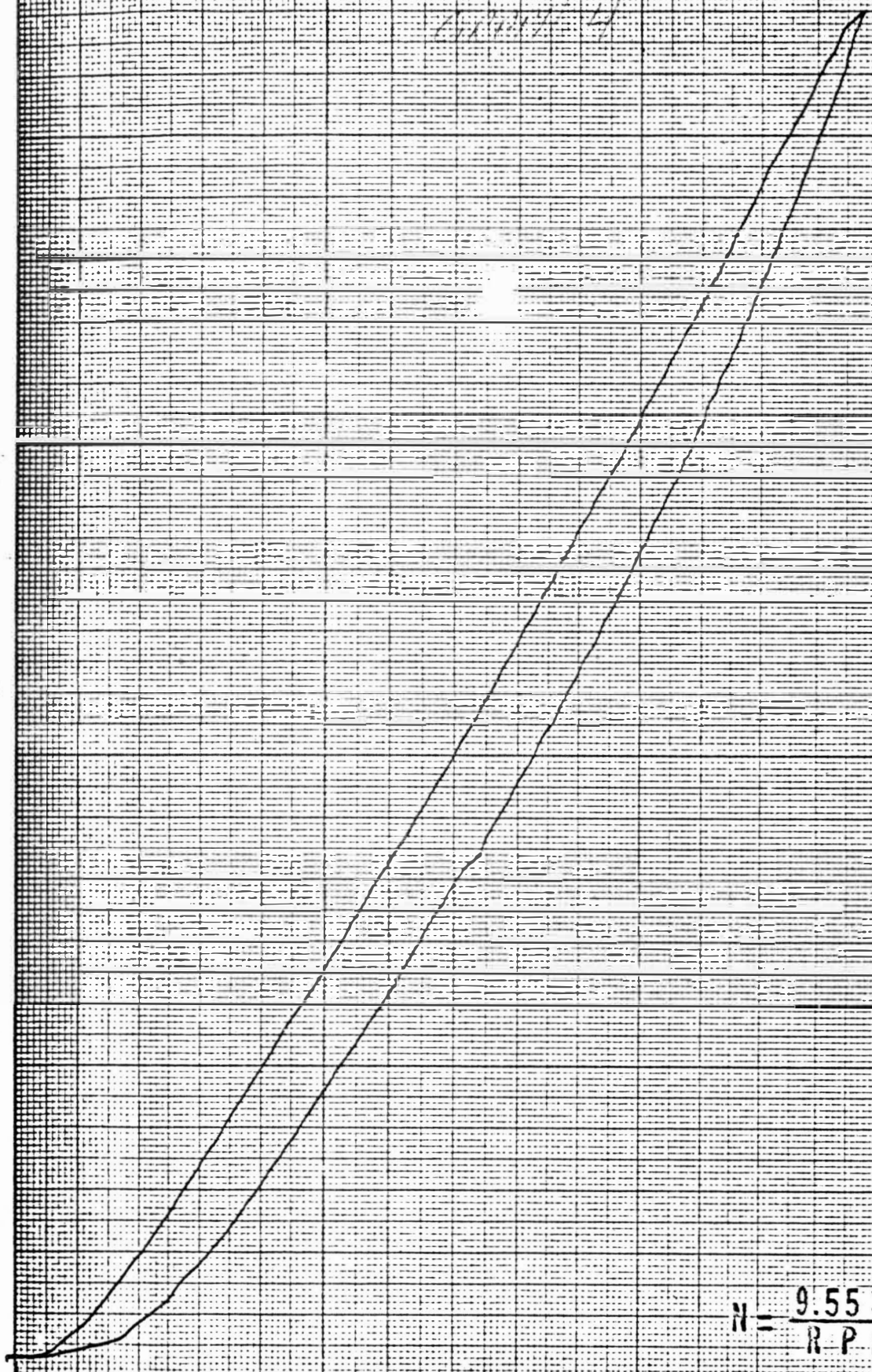
Clay	Thixotropic Index (DYNE CM)	Apparent Newtonian Viscosity (POISE)	Leveling Index (CM/SEC)	Form of Flow
Hydragloss	95,000	0.5339	177,935	Plastic
C-1	105,000	0.4884	214,987	Plastic
C-2	145,000	0.6142	236,079	Plastic
C-3	125,000	0.5990	208,681	Plastic
C-4	160,000	0.5686	281,393	Plastic

47% SOLIDS

Hydragloss	65,000	0.4341	149,735	Psuedoplastic
C-1	55,000	0.3798	144,813	Psuedoplastic
C-2	75,000	0.5057	148,309	Pseudoplastic
C-3	70,000	0.4753	147,275	Pseudoplastic
C-4	110,000	0.4927	223,259	Pseudoplastic

Q-3, 120-16 STARCH
 50.125 51.40%
 11/17/44

R P M



TORQUE

$$N = \frac{9.55 \times T \times S}{R \cdot P \cdot M}$$

KALTEC SCIENTIFIC INSTRUMENT, INC.
 P O Box 348 • 327 E. Ransom St • Atlanta, GA 30306

S	BOB HEIGHT CM	RADIUS CM	INSTRUMENT	MAX. RATE OF SHEAR (Velocity Gradient) 1/sec.			
				550 RPM	1100 RPM	2200 RPM	4400 RPM
A	5.0	1.95	.00020	2275	4549	9098	18196
B	2.5	1.95	.00040	2275	4549	9098	18196
C	1.0	1.95	.00037	2275	4549	9098	18196
D	.75	1.50	.00520	193.5	387	774	1542

PIGMENT AND PROTEIN
50% SOLIDS

Clay	Thixotropic Index (DYNE CM)	Apparent Newtonian Viscosity (POISE)	Leveling Index (CM/SEC)	Form of Flow
Hydragloss	85,000	0.5578	152,384	Plastic
C-1	145,000	0.5560	260,791	Plastic
C-2	195,000	0.5708	341,625	Plastic
C-3	190,000	0.5643	336,700	Plastic
C-4	215,000	0.6316	340,405	Plastic

C-9 + 10.75 PROPER
 12.103 50.0%
 C-10.75

R P M

$$N = \frac{9.55 \times T \times S}{R P M}$$

TORQUE

KALTEC SCIENTIFIC INSTRUMENT, INC.
 P.O. Box 348 • 327 E. Ransom St. • Kalamazoo, Mich. 49006

	BOB HEIGHT CM	RADIUS CM	INSTRUMENT S	MAX. RATE OF SHEAR (Velocity Gradient) 1/sec.			
				550 RPM	1100 RPM	2200 RPM	4400 RPM
A	5.0	1.95	.00020	2275	4549	9098	18196
B	2.5	1.95	.00040	2275	4549	9098	18196
C	1.0	1.95	.00097	2275	4549	9098	18196
D	2.5	1.50	.00520	1935	387	774	1543
E	1.0	1.00	.00008	6737.5	11475	22950	45900